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Decision Support for Water Resource Management: Integration of Water Control and Water Quality Data

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PURPOSE: In recent years, there has been increased focus by the U.S. Army Corps of Engineers and other federal agencies on a system-wide approach to watershed management as a means to enhance stewardship and protect the Nation's water resources. Because of this, new approaches to decision support that integrate across political, technological, social, economic, and physical considerations are needed. This will require development of tools and techniques to evaluate management operations for multiple objectives (e.g., economic development and environmental quality) and multiple purposes (e.g., flood control, navigation, hydropower, and fish and wildlife habitat) and to establish trade-offs among competing objectives. A critical element of these system-wide tools will be the ability of the water resources manager to access and utilize diverse spatial and temporal information. Results of initial efforts to integrate water control and water quality data into a spatially explicit decision support tool are described here.

BACKGROUND: Growing concern over the quality of the Nation's water resources has prompted new legislation and more stringent enforcement of current environmental regulations, and underscored the need to develop and apply new resource management tools. Increases in population and changes in land-use patterns have accelerated the rate at which contaminants, sediments, nutrients, and other materials impacting water quality are transported from watersheds to rivers, lakes, reservoirs, and wetlands. The result has been a progressive deterioration of water resource quality.

The Corps currently maintains and operates approximately 750 water resource development projects (Kennedy 1999). Project purposes include flood control, hydropower, navigation, water supply, and fish and wildlife. Management concerns at several of these projects range from impaired downstream water quality (e.g., low dissolved oxygen concentration, sub-optimal water temperature, and elevated concentrations of reduced metal, including iron and manganese) to eutrophication of reservoir pools, including elevated algal biomass and reduced hypolimnetic dissolved oxygen concentrations (Kennedy and Gaugush 1988). While reflective of the impacts of inputs of material (e.g., nutrients, sediment, etc.) from the watershed, many of these conditions are influenced by project operation. Because of this, water quantity and water quality are logically linked in the decision-making process.

The Corps, and other water resource development agencies with similarly broad missions, have developed comprehensive management strategies based on the allocation of flow and storage volume within and among projects so as to optimally meet project-specific and basin-wide water control objectives. The collection, maintenance, and use of hydrologic information support this management strategy. In addition to project descriptions (e.g., area/capacity relationships, etc.) and meteorological information, time-series data (e.g., stage elevation and discharge) are routinely collected at points within the system. Together, these data allow water control decisions to be made on both a project and basin-wide basis.

Water quality management, while implicitly acknowledging broad-scale patterns, has traditionally involved the collection and analysis of water quality data for discrete locations. As a result, spatial interdependence is frequently overlooked and management decisions are made on a location-by-location basis. Traditional water quality monitoring approaches have involved the establishment of sampling points or stations at convenient or representative locations and the routine collection of water quality information at these sites. Sampling strategies include the collection and subsequent analyses of water samples, and in situ measurement of variables using electronic sensors (e.g., water temperature, dissolved oxygen, specific conductance and pH). The latter strategy often involves the collection of measurements over relatively short time intervals (e.g., minutes or hours) to create a nearly continuous record of time-varying changes in water quality variables.

Linking diverse data can provide a robust approach to effective management. Since coincidental assessment of water control and water quality information acknowledges the intrinsic relationships between operations and water quality, environmental concerns can be included more explicitly in the decision-making process. The objectives of this effort were to (a) design a data integration/analysis system to support resource management activities, and (b) to demonstrate its application to selected Corps water resource projects.

SYSTEM DESIGN AND DEVELOPMENT: Coincidental access to both water control and water quality information is the key requirement of an effective decision support system for basin-wide water resource management. To accomplish this, a range of information types from diverse sources must be managed and available for retrieval and subsequent analysis within a seamless environment. While water operations data are routinely stored in HEC-DSS (U.S. Army Engineer Hydrologic Engineering Center (HEC) 1995) with uniform format, water quality data are stored in a variety of formats and software settings. In addition, water quality data are frequently analyzed using numerous and varied software utilities. Thus, a common, seamless user interface is required.

Existing software utilities were assessed for their ability to perform as components of an integrated data management, analysis, and display system. As a result of this assessment, CorpsView, a map-oriented display interface providing access to water control data stored in HEC-DSS, and DASLER, a recently developed Windows-based data management and display program, were selected as the basis for the integrated decision support system described below.

CorpsView. CorpsView is a water control data visualization tool developed to provide access to and display of water control time series data and model results from within a geographic map interface. It was developed as part of the Remote Sensing Research Program. CorpsView is an extension to the UNIX ArcView GIS software package (ESRI, Redlands, CA) containing tools developed by the Cold Regions Research and Engineering Laboratory (CRREL) to display HEC-DSS time-series data, HEC-RAS inundation data, and other model results (Figure 1). Users can select from multiple map views of project areas, click on gauges within these views to obtain real-time DSS data in plot or tabular form, and load inundation maps generated through models to spatially overlay with base map data. All spatial data supported by ArcView can be utilized, including ArcView Shapefiles, ARC/INFO coverages (ESRI, Redlands, CA), Digital Line Graph (DLG) from the U.S. Geologic Survey and Computer Aided Design (CAD) data, remote sensing imagery, and scanned photography. CorpsView is a component of the Corps Water

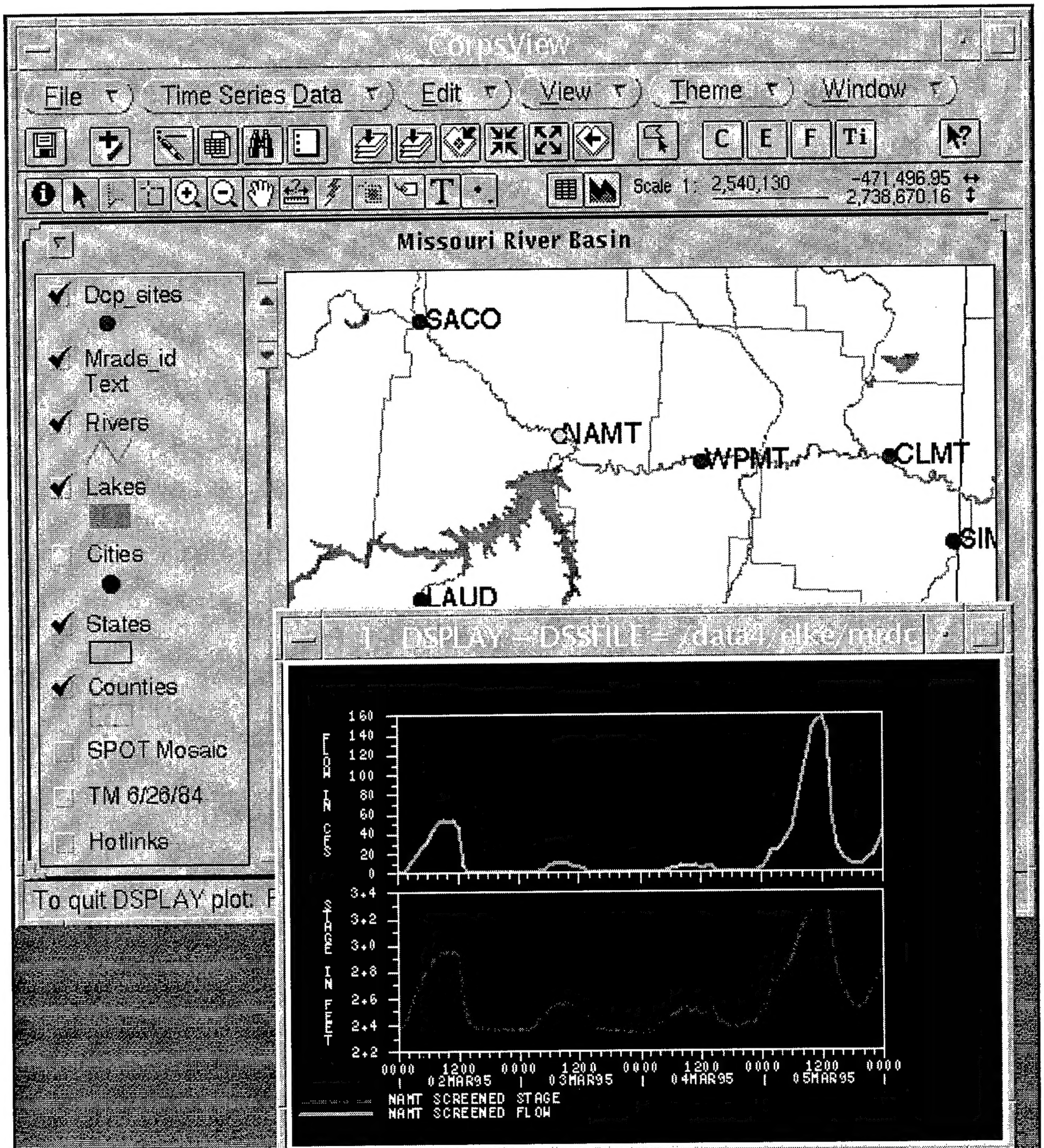

Figure 1. CorpsView map display of a reach of the Missouri River Basin. Inset display is based on HEC-DSS data for temporal changes in discharge (upper; green) and stage (lower; red) at station NAMT

Management System (CWMS) and is being deployed Corps-wide. CorpsView is currently installed at 20 Corps' Districts and Divisions (Figure 2).

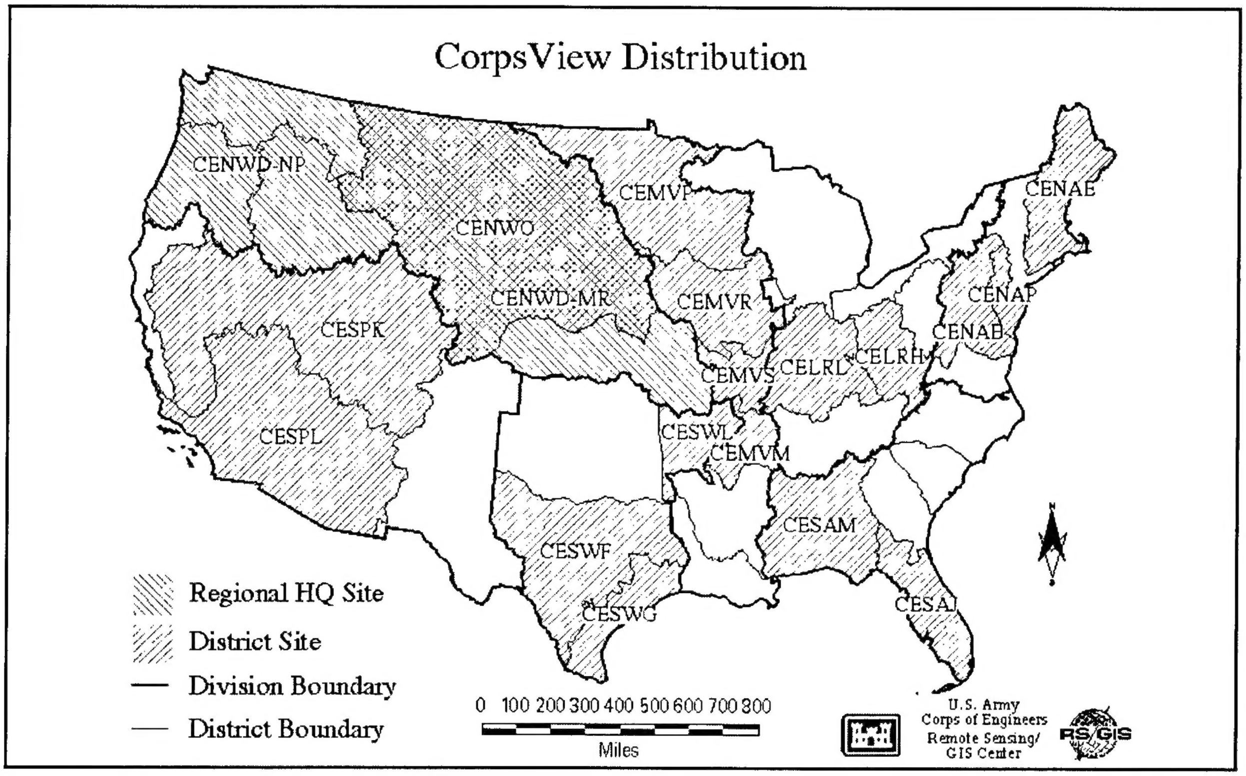

Figure 2. Corps of Engineer Districts and Divisions at which CorpsView has been installed (as of February 2000)

DASLER. The Data Management and Analysis System for Lakes, Estuaries, and Rivers (DASLER) is a Windows-based program designed to manage and report many types of water quality data (Burnett 1999). Data are concentrated into two broad categories: physical/chemical and biological. The main DASLER interface provides a central management point for both categories, with special functions tailored to the specific needs of each section. DASLER uses the same database engine and database file structure as Microsoft Access. The database engine can communicate with any SQL database. This allows individual installations to use their database software of choice, as long as an open database connectivity (ODBC) driver exists for that software. For instance, one installation may be using Oracle while another uses the native Access format. The DASLER suite includes plotting software (Hydrologic Information Plotting Program; HIPP) that produces a variety of standard plots from data. HIPP interacts with DASLER or runs as a stand-alone program. Plots are highly customizable and can be printed on any Windows printer or saved as metafiles. Plot settings can be saved as custom templates. Some installations of DASLER also include a GIS-based interface to the water quality data.

System Integration. Coincidental access to both water control and water quality data requires integration of capabilities provided by CorpsView and DASLER. CorpsView currently provides map-oriented access to water resource operations data stored in HEC-DSS as an ArcView application. The locations of DCPs (data collection platforms) and water quality data collection sites are

displayed on a reference map and object-oriented features on the map allow users to request associated data. HEC-DSS provides hydrologic information (e.g., discharge and stage) in tabular form or as graphical displays using the DSPLAY option. Other maps and displays, including photographs and images, are also available as ArcView layers. DASLER, recently developed for the U.S. Army Engineer District, Nashville,[1] as the primary input and analytical interface for environmental data maintained in their EquIS (Environmental Quality Information System; Earth-soft Inc., Pensacola, FL) database, provides access to water quality and related information.

User-defined graphical displays of numerical information are provided by HEC-DSS/DSPLAY and DASLER/HIPP, and can be viewed through the same CorpsView interface. In addition, individual data analyses and displays can utilize data from both HEC-DSS and DASLER. Coincident queries are initiated by CorpsView to DASLER and HEC-DSS using Avenue scripts (Figure 3). In the case of DASLER, the Avenue scripts are prompted by clicking on water quality stations. These scripts run automated SQL commands to access and display water quality plots, tables, and charts. For HEC-DSS queries, these Avenue scripts run DSPLAY and DSSUTL macros, which respectively graph or tabulate data from water control stations.

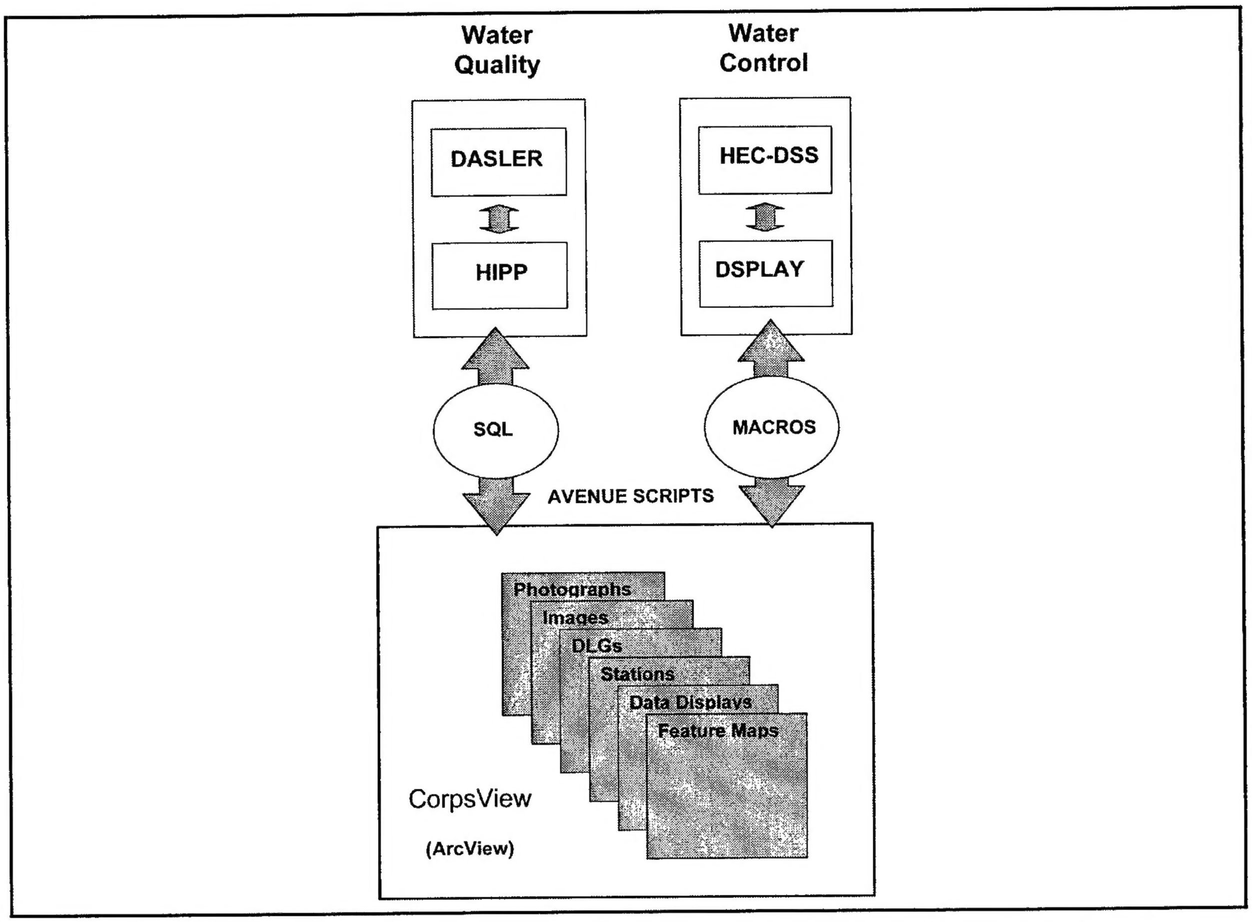

Figure 3. Component parts of CorpsView_WQ for integrating water control and water quality information (see text for a more detailed explanation)

1 Personal Communication, 2000, Mr. Robert Sneed, U.S. Army Engineer District, Nashville.

The combined querying ability of CorpsView_WQ (CorpsView/Water Quality integrated decision support system) will allow for coincident queries from improved decision support tools. The water resources manager will be able to produce queries that will generate explicit reports showing the relationships between project operations and water quality. Coincident graphical reports such as reservoir releases/vertical distributions in dissolved oxygen, or tributary inflows/mainstream water quality are examples of the value-added information that can be obtained.

EXAMPLE APPLICATIONS: The following examples demonstrate the performance and typical applications of CorpsView_WQ. Example data and environmental information presented here were obtained for the Nashville and Huntington Districts. Additional data for selected projects in Huntington District were collected as part of the Water Quality Research Program (Kennedy, Meyer, and Cremeans 1999).

Figure 4 is an example of a CorpsView map layer indicating the location of hydrologic monitoring sites, as well as water quality sampling locations for the Kanawha River Basin (Huntington District). For many applications, this object-oriented map provides a means to select data locations and to

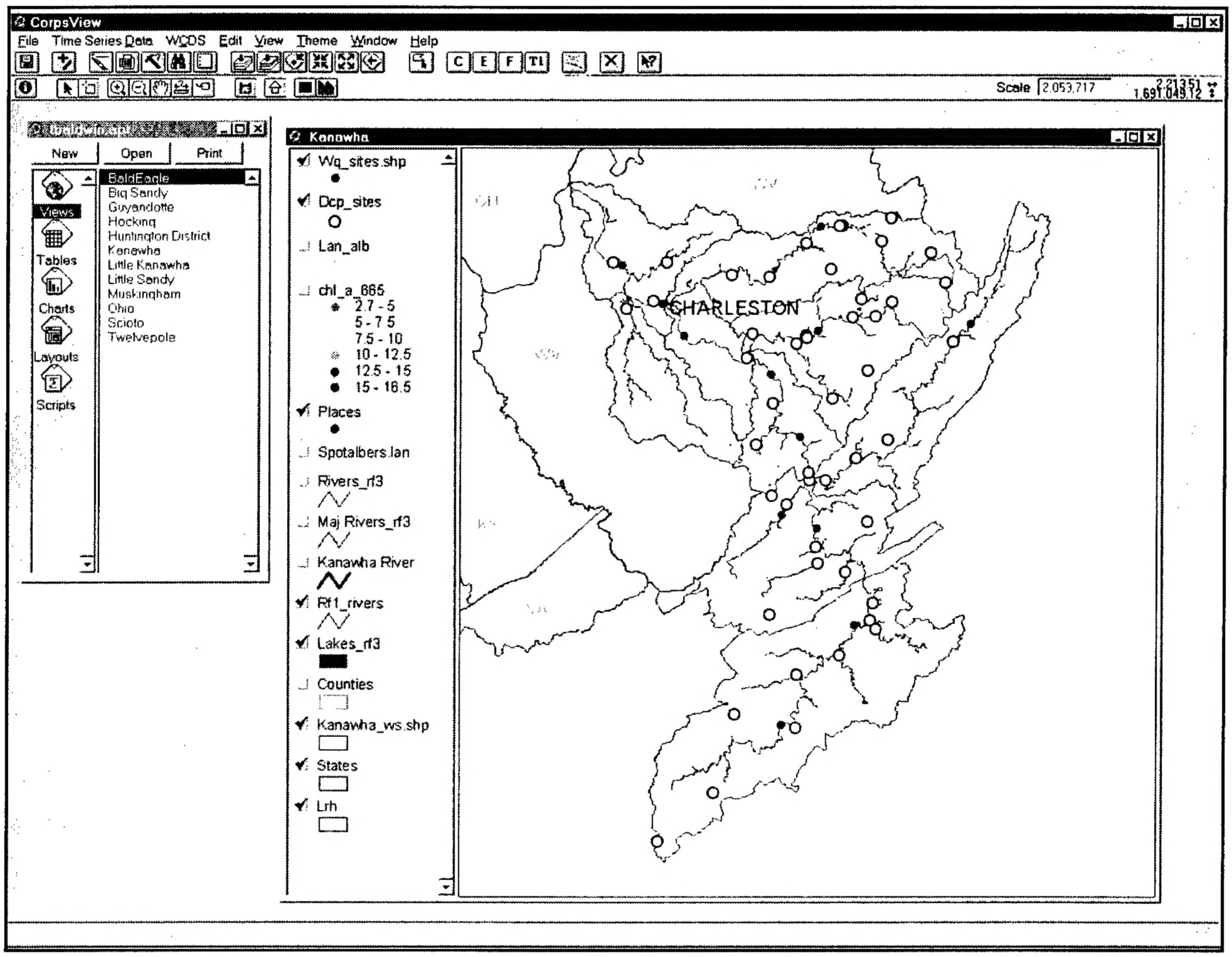

Figure 4. CorpsView_WQ map display indicating the locations of hydrologic (yellow) and water quality (red) data collection locations for Kanawha River Basin, WV. Note that categorical station symbols can be included as a means to identify sites that do not meet a user-defined expectation (e.g., chlorophyll concentration that exceeds a standard or threshold value)

initiate queries from both DASLER and HEC-DSS databases. Queries typically specify temporal limits and desired variables.

Figures 5 and 6 are examples of typical data displays. These include XY plots and contour plots. Vertical distributions in dissolved oxygen concentration and water temperature for a single station and date are plotted versus sample depth in Figure 5. Temporal changes for these variables at a single station are also displayed in Figure 5. In both cases, CorpsView_WQ provides the means to select and plot multiple Y variables versus a single X variable. Symbol/line types and colors can be selected by the user.

Contour plots offer visual access to complex datasets, and provide insightful information about trends in space and across time. Figure 6 presents contour plots of changing dissolved oxygen concentrations over time at a single station and across multiple stations on a single date. Since pool surface elevation changes over time, pool elevation data obtained from HEC-DSS have been included in Figure 6 and sample depths have been converted to elevation. Figure 6 also incorporates morphometric data to allow portrayal of the changing bottom profile between sampling stations.

Photographs and images can provide valuable management information since they allow identification of important features and structures. The association of spatially referenced numeric data with photographs and images allows the user to assess spatial setting and to infer potential cause-and-effect linkages. Figure 7 is an example display for a reach of the Kanawha River, WV, incorporating an image (SPOT satellite image), HEC-DSS data (stage and flow), and water quality data (surface chlorophyll concentrations collected from a moving boat at the approximate time of the satellite overpass). This display provides value-added information since it allows visualization of watershed features potentially influencing observed water quality patterns in the water body.

CONCLUSIONS: CorpsView_WQ is an easy- to-use tool for accessing, displaying, and assessing diverse information related to water control and water quality. A common, map-oriented graphical interface allows water resource managers to evaluate the wide range of information required for making sound management decisions. Full installation and trial application of CorpsView_WQ is ongoing at the Huntington District.

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www.wes.army.mil/el/elpubs/wqtncont.html

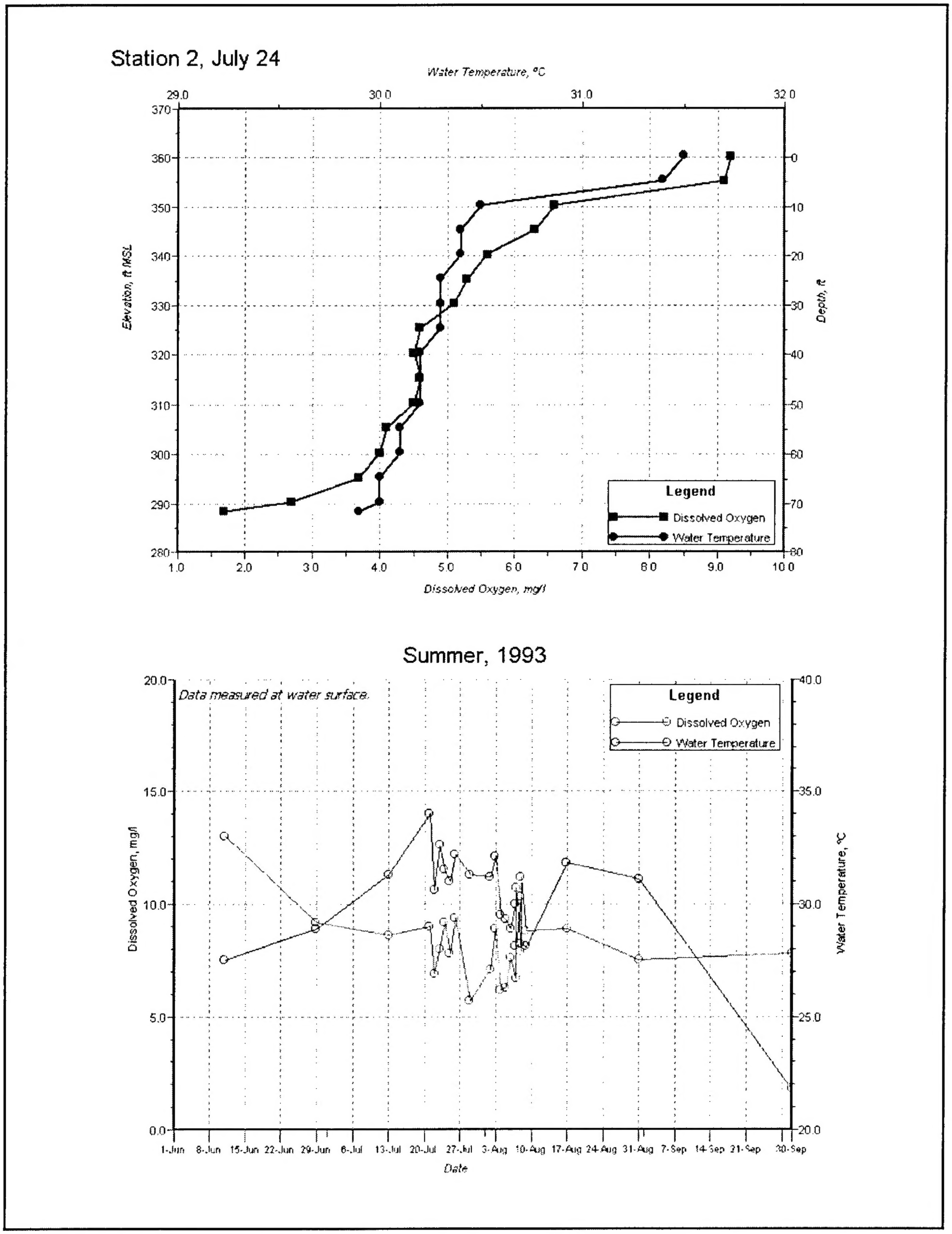

Figure 5. XY line plots generated by DASLER/HIPP. Dissolved oxygen concentration (red) and water temperature (blue) are plotted as a vertical profile (upper) and as changes over time (lower)

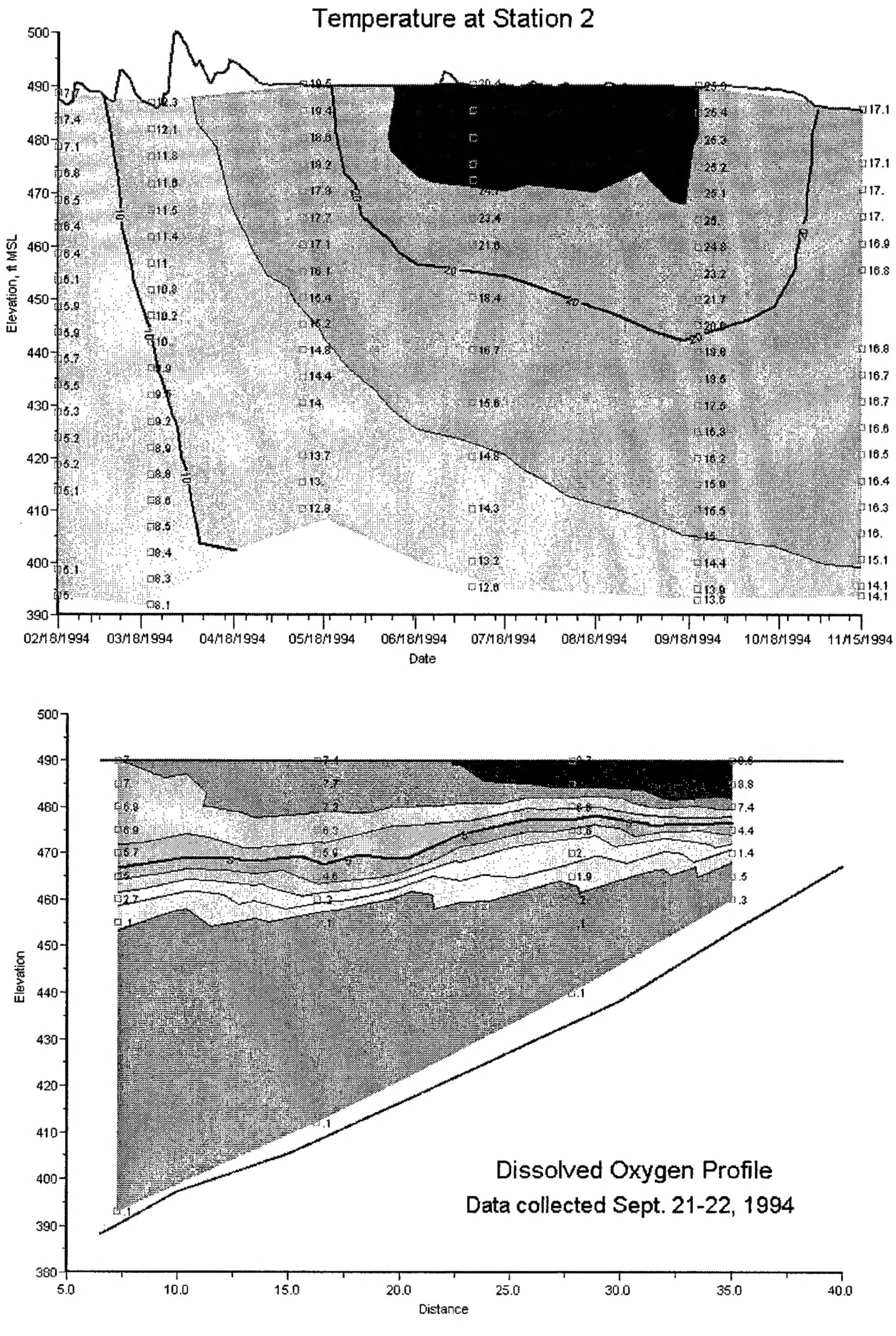

Figure 6. Contour plots generated by DASLER/HIPP. Dissolved oxygen concentration is plotted versus depth and time (upper) and as changes across stations (lower). Red lines indicate surface and bottom elevations

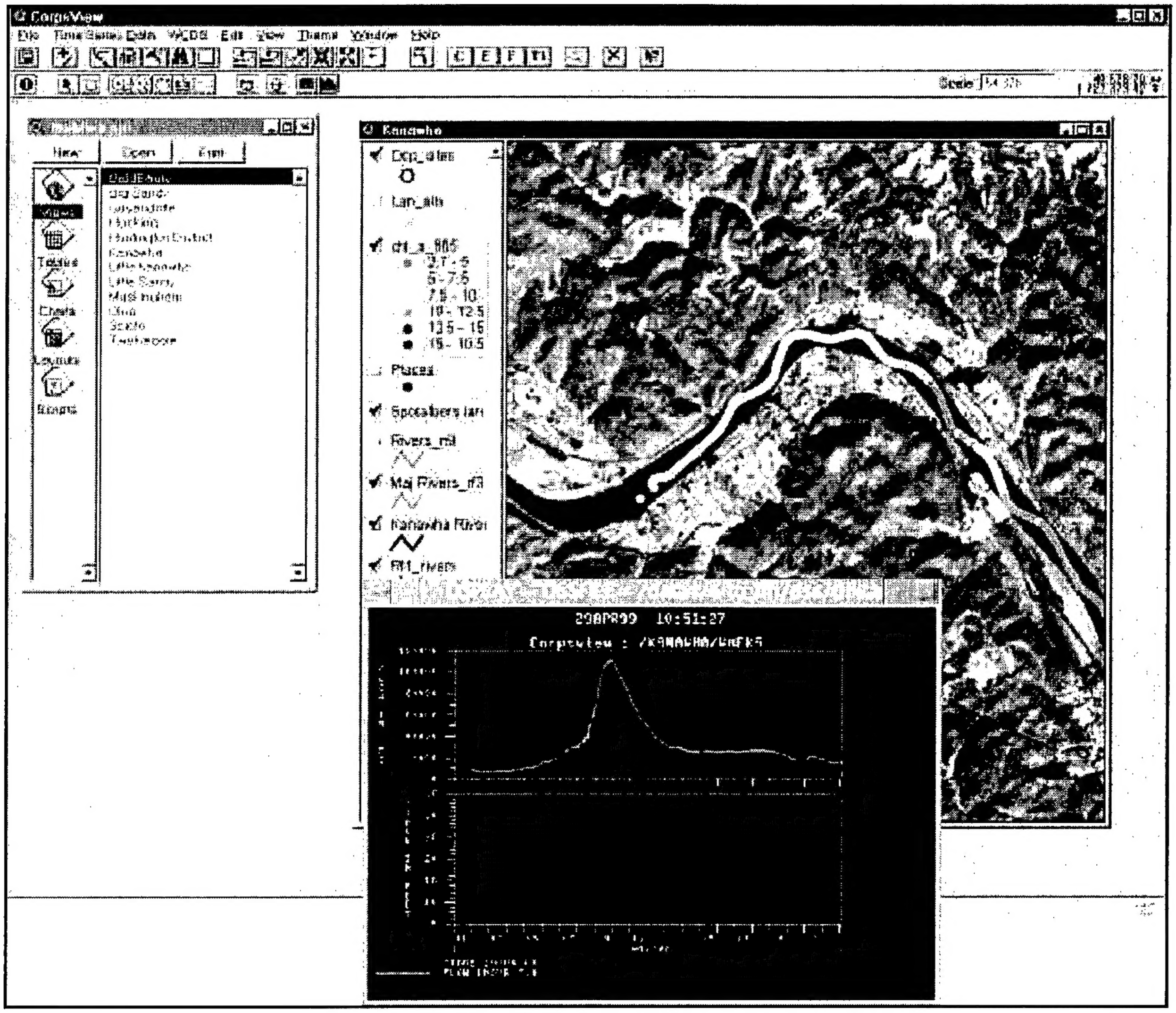

Figure 7. Example display demonstrating the integration of HEC-DSS data (inset), satellite (SPOT) image data and chlorophyll concentration (green-low, red-high) for a reach of the Kanawha River, WV. Chlorophyll data collected as part of a joint LRH and ERDC/EL study (Kennedy, Meyer, and Cremeans 1999)

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